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How Can Research Production Be Measured? [1]

GEORGE A. ROUNSEFELL
U. S. Bureau of Commercial Fisheries
Galveston, Texas

THOSE RESPONSIBLE FOR THE ADMINISTRATION of research programs find it very difficult to judge whether progress is satisfactory. How can we measure this progress? We must first decide what kind of information should be produced and how this information should be communicated to other research workers, to action levels of administration, to any affected industry, and to the general public.

In answering the question concerning the type of information required, a sharp distinction must be drawn between management and research. A biologist may gather routine data to give management continuous information needed to insure intelligent use of a resource. This is not research. Should these data also prove adequate on analysis to throw new light on some aspect of biology, it would be fair to charge some portion of the cost of collection to research. In many cases, however, an experiment can be designed to bring out the biological facts at less cost, and in more clear-cut fashion, than by using data collected for other purposes. This was well exemplified in Alaska for years before statehood. The problems of management were so great and so pressing that the federal research biologist had to spread his field activities over wide areas and gather data to answer specific questions needed for management in particular localities.

If such a situation were recognized and sufficient funds and personnel made available, perhaps this handicap could be overcome. In the case cited, however, the inevitable siphoning of already inadequate research funds into quasi-research activities delayed the acquisition of basic biological information. In the long run, management suffered from failure to discover some of the underlying biological principles sorely needed for wise management.

Let us then define research as the search for new knowledge. And let us not quibble about basic and applied research. The idea of research for the sake of research and anxiety to avoid the stigma of identification with any organism or process beneficial to man is not a useful concept. There is no dividing line between "basic" and "applied" research. Biological principles may be elucidated through the study of any species whether or not it is currently useful to man.

The second question—communication—has plagued scientists for years.

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There is often a long gap between the completion of a piece of research and the appearance and dissemination of a technical report. In fact, this is one of the main arguments favoring annual reports of research groups chronicling the progress and stage of completion of each research project.

Following a technical report on a research project there often arises need for translation of the report into a summarized and simplified account of the facts or principles studied, with some evaluation of their significance. Research personnel are therefore expected also to turn out material of a popular or semi-popular nature, as well as minor reports on techniques, methods, research outlines, translations, abstracts, informational leaflets, raw data reports, and so forth. Although none of these latter reports can take the place of the technical report, they are of undoubted value, and the authors deserve credit.

This leads us to the crux of the problem. Simply stated it is, "How do we determine whether progress is satisfactory?" Research progress cannot be measured in terms of dollars spent, laboratories built, or file cases stuffed with observations. Essentially a mental discipline, it cannot be sequestered or evaluated until transposed to paper. Only by evaluation of the written report, the final product, can we judge whether progress is satisfactory. Furthermore, in practically all cases in which research projects have for any reason been abandoned before a final report was written, a waste of funds has resulted. The published report then, of necessity, will be used as our yardstick of progress.

The problem now resolves into the determination of two things: (1) How much effort went into the production of a report, and (2) What is the relative worth of any individual report.

Money alone is a poor yardstick of effort. It often costs more to perform a stated amount of research in one locality or discipline than in another. Whether to continue the more expensive operation usually remains a policy decision. However, in judging performance at any two locations it would be patently unfair to judge effort by the amount of funds. This becomes especially noticeable when comparing costs of inshore research with mid-ocean research entailing large vessels and crews.

Facilities in terms of offices, laboratories, and vessels are not readily comparable. The nature of the problem largely determines the cost of the necessary facilities. A biochemist requires a well-equipped chemistry laboratory, a field biologist may occupy a small office, but require a car, a small vessel, perhaps field aids. In each case the researcher is provided with the means, whether cheap or expensive, to perform experiments or gather field data in order to solve a particular problem. In judging research production then, we must assume that each researcher has been provided with facilities in accordance with his needs. When production is below standard, facilities should be scrutinized, since research facilities are rarely fully adequate.

Since we have eliminated both funds and facilities, there remains the research man himself as our unit of effort. Because research is primarily a mental process, the bottleneck to production at many laboratories is the small number of scientists with the ability to analyze raw data, devise adequate tests of hypotheses, make logical deductions, and then convert these conclusions into intelligible reports.

Use of the scientist himself as the unit of research effort entails the question of whether or not we should recognize categories of effort, say between junior

and senior scientists. The use of categories is difficult for many reasons: different research groups have a different number of categories, and promotion and salary rates vary so that it would be difficult to establish comparable ratings. Moreover, ratings do not necessarily reflect either ability or experience. Although productivity usually increases with time, it often reaches a peak; thereafter it may tend to decline as the researcher—now an incipient administrator—is given more and more outside duties. Moreover, the length of time spent in each grade will vary with availability of funds. Examination of publication records indicates that it normally takes about 4 to 5 years for a man to reach a high rate of productivity.

Having decided on the scientist as the unit of research effort we come to the difficult task of deciding on the method of evaluating publications produced by the researchers. Because of the difficulty of evaluation, there has long been a tendency to rate scientists on the number of published articles. However, the mere enumeration of titles is almost worthless in assessing production. Some titles represent but a few hours of work; others are the culmination of several years of dedicated endeavor. To place them on the same footing is to make a mockery of science and discourage honest diligence.

Thus it is understandably discouraging to the dedicated research worker to read an announcement that so and so, who has just been hired, promoted, or given some honorary post, has published 50 or 60, or perhaps 80, scientific articles. After racking his brain the poor worker can remember perhaps three or four articles. Where did the rest come from? If we allow for some over-publicity, we may find the list was actually only 45 articles. Ten were semi-popular articles in trade journals, another 10 were short notes on species distribution, perhaps 8 were general science notes in the journal of a local academy of science, 4 or 5 were published as abstracts (meaning an article on the subject may be forthcoming someday, if and when), several were processed (often merely a polite term for mimeographed) reports that never got far beyond the local office, the remaining 8 or 9 articles may have included 2 or 3 really worthwhile scientific contributions. This is not an attempt to indict the voluminous writer, but merely an example of how the use of false values in measuring research production may sometimes lead to erroneous conclusions.

In evolving an objective method for rating publications of research personnel, it should be emphasized that the primary function of research is to produce new knowledge. As a consequence, stress is placed on those articles which lay the foundations for new facts or principles. If a research worker can obtain sufficient publication credit by putting out progress reports and semipopular filler, he may never be persuaded of the necessity for concentrating on the kernel of his subject.

There will always be some criticism of any method of rating publications because their valuation is somewhat dependent on the point of view of the appraiser. Ratings must also bear some relation to the effort required to produce them. By effort, we do not mean physical labor; we reiterate that research is a mental process. After some study, I have evolved a system that attempts to encourage the writing of good technical reports, at the same time giving credit for all types of articles related to research.

The reports have been grouped into six categories based largely on content as follows:

Category A:
Original research requiring extensive analysis or original thought published in a scientific journal, or as a textbook or reference of college level. May include articles describing original techniques and apparatus.

Category B:
Research employing known techniques such as stream surveys, censuses, routine sampling when analysis is not extensive. Includes doctoral dissertations, revisions of textbooks or references, and taxonomic descriptions, keys, or reviews.

Category C:
Narrative and informational reports of scientific merit not requiring analysis. Includes general books or chapters on conservation, encyclopaedia articles, and technically correct information bulletins.

Category D:
Reports designed to make raw data available which may include short descriptions of methods and procedures but no analysis. Includes bibliographies, faunal lists, and glossaries.

Category E:
Semi-popular and popular articles, short descriptions of research programs, summaries of research accomplishments.

Category F:
Short faunal notes on species range, etc., critical book reviews, articles published only as abstracts, technical research notes in annual laboratory or commission reports, semipopular articles published in newsprint journals (not in newspapers).

The division of page credit between authors for multiple-author reports is shown in Table 1.

TABLE 1

PER CENT OF PAGES CREDITED TO EACH AUTHOR TO THE NEAREST ONE-HALF PAGE[1]

Number of authors	Position of author's name 1	2	3	4	5
1	100				
2	60	40			
3	50	30	20		
4	40	30	20	10	
5	40	30	20	10	0

[1]In case of a tie the extra one-half page belongs to the more senior author.

To obtain adequate material for a study of research production we have analyzed the publications of 60 scientists of the Fish and Wildlife Service during the 17-year period from 1940 to 1956, inclusive. No one was included with less than 10 years of work during the period; 32 worked for the entire 17 years.

First we determined the relative number and length of publications by type (Figure 1 and Table 2). This shows that out of 896 articles (solely or partially authored by one of our sample) 64 per cent were published outside of the Service. However, the articles published outside averaged but 12 pages in

TABLE 2

ACTUAL PAGE LENGTH OF ARTICLES BEARING NAMES OF THE 60 SCIENTISTS SAMPLED

Pages	Category A FW	A O	A T[1]	B FW	B O	B T	C FW	C O	C T	D FW	D O	D T	E FW	E O	E T	F FW	F O	F T	Total FW	Total O	Total T
1-5	20	33	53	27	9	36	34	15	49	2	1	3	5	114	119	7	116	123	95	288	383
6-10	15	59	74	21	22	43	23	10	33					27	27		3	3	59	121	180
11-15	5	28	33	5	12	17	5	6	11	2	1	3		2	2				17	49	66
16-20	13	18	31	7	8	15	7	1	8	3	1	4		4	4				30	32	62
21-30	16	16	32	8	13	21	9	3	12	6	1	7		1	1				39	34	73
31-40	6	6	12	4	12	16	3		3	2	3	5					1	1	15	22	37
41-50	3	2	5	5	4	9	2	1	3	1		1							11	7	18
51-60	7	1	8	1	3	4				3		3							11	4	15
61-70	3		3	3	2	5	1		1	1		1							8	2	10
71-80		4	4	4	1	5				5		5							9	5	14
81-90	3		3	1		1													4	0	4
91-100				2		2				1	1	2							3	1	4
101-110	1		1	4		4	1	1	2	7		7							13	1	14
> 110	3	2	5	1	3	4	1	1	2	5		5							10	6	16
Number	95	169	264	93	89	182	86	38	124	38	8	46	5	148	153	7	120	127	324	572	896
Per cent	36	64		51	49		69	31		83	17		3	97		6	94		36	64	
Ave. No. Pages	27	15		25	24		14	16		63	32		3	5		3	3		26	12	17

[1]FW — Fish and Wildlife; O — Other; T — Total

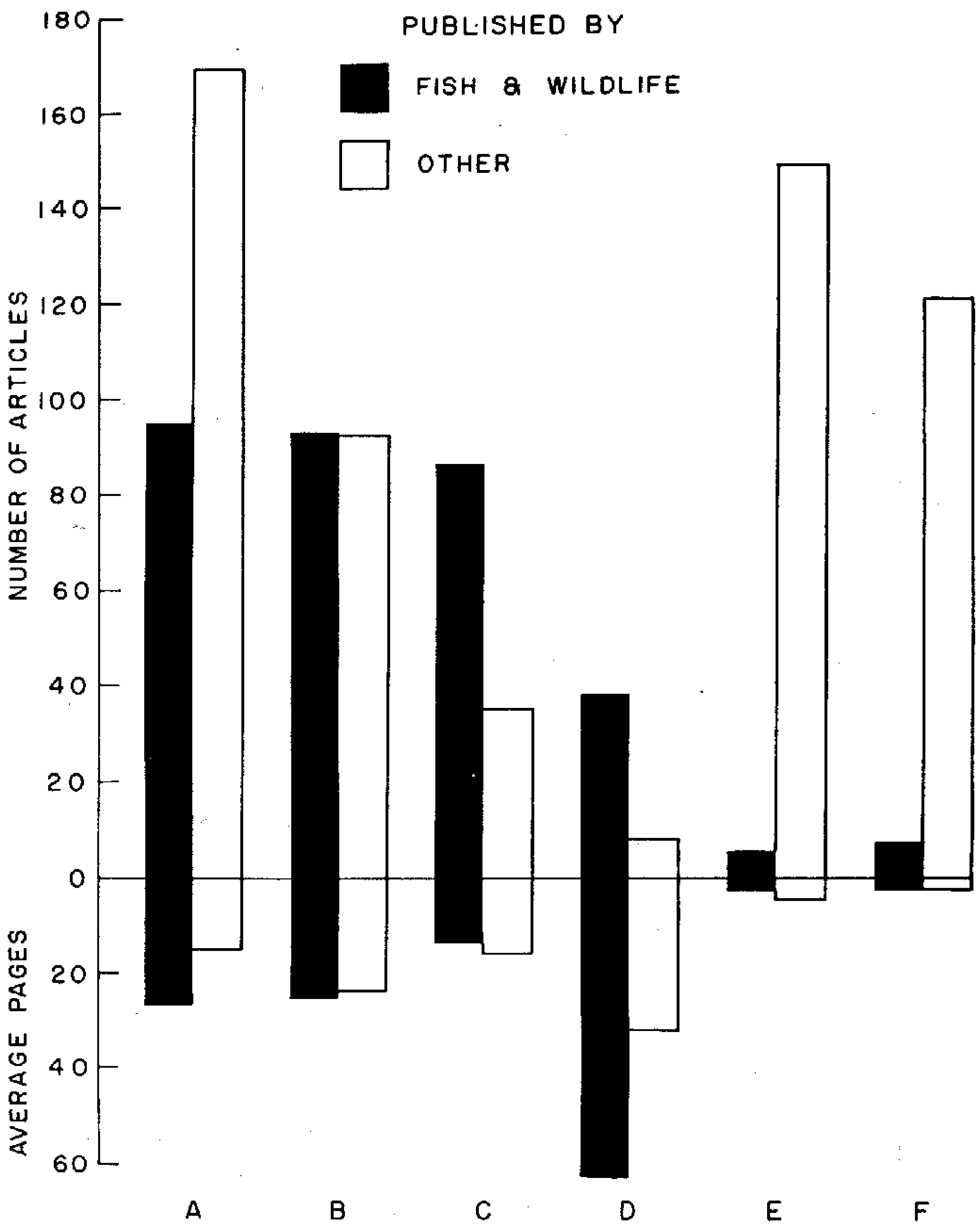

FIGURE 1. Number and length of articles by categories bearing the name of one of the selected group of 60, 1940-56.

length compared to 26 pages for Service publications, so that the Service actually published 56 per cent of the pages. Of the articles requiring most research analysis (A Category) the Service published only 36 per cent of the articles, but 50 per cent of the pages.

The great number of very short articles in the E and F categories (which do not require extensive research) demonstrates that number of articles published would be a very unreliable index of research production.

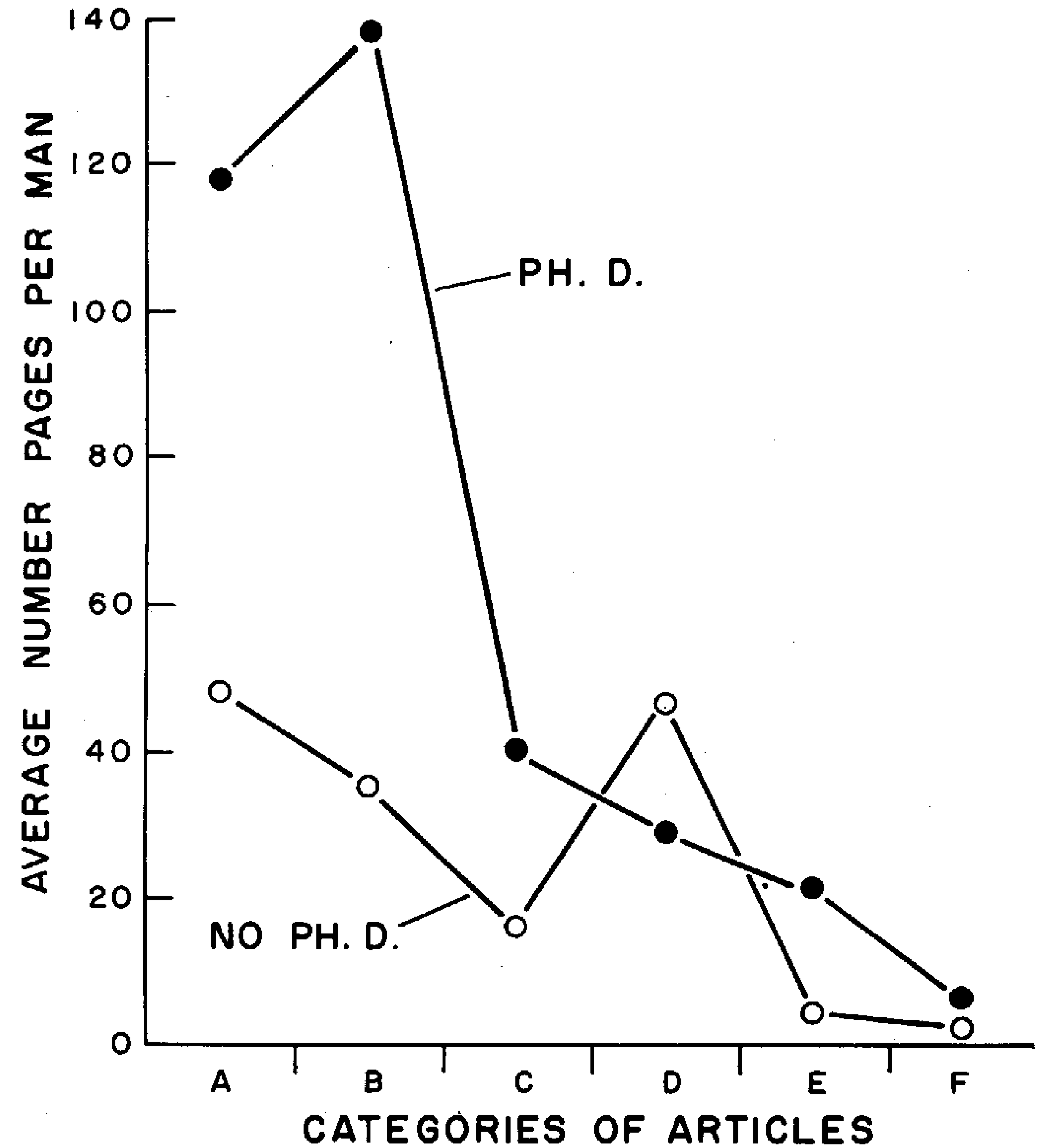

FIGURE 2. The average number of pages according to category, published per man on a 17-year basis by scientists with and without the doctorate.

That the number of pages published is also not too reliable an index is shown by the great length of the articles in Category D, which are chiefly raw data. It should be observed that only 16 of our sample of 60 published an article in this category. This is the only category in which those with Ph.D.'s published less pages per man than those without (Figure 2).

Obviously neither number of articles, nor number of pages can serve as an index. The number of pages published would be fairly reliable if it were not for the great variation between categories in the value of the product. The only practical solution is to use the number of pages weighted by categories according to their relative contribution to research.

TABLE 3

ADJUSTED PAGE CREDITS OF 60 SCIENTISTS BY ACADEMIC TRAINING AND FIELD OF WORK

Adjusted page credits	Without doctorate degree				With doctorate degree				Total	
	Anadromous	Inland	Marine	Other	Anadromous	Inland	Marine	Other	Without doctorate	With doctorate
0-200	6	1	1	1					9	
201-400	4	1	2						7	
401-600	5				1				5	1
601-800	1	2	2	1			1	1	6	2
801-1000			2	1		1	1		3	2
1001-1500		1	2			3	2		3	5
1501-2000			2			1	1	1	2	3
2001-2500		1	1		1	1			2	2
2501-3000			1	1			1		2	1
3001-4000						1	1			2
4001-5000						1	1			2
5001-6000										
6001-7000								1		1
	16	6	13	4	2	8	8	3	39	21

The relative weights of each category employed in my analysis are:

A - 10
B - 5
C - 3
D - 0.5
E & F - 2

The compilation and listing of raw data, the tedious and meticulous listing of bibliographic references, or the listing of species distributions require care and exactitude but not deep scientific thought. It must also be remembered that practically every good research paper sprang from a large quantity of raw data that had to be meticulously listed and tabulated prior to the actual analysis for the research paper. Because some of these original data are made available (almost universally now by photo reproduction) in multilith form, hardly entitles the author of a 25-page research paper to claim much credit for releasing 250 pages of listed data. On a basis of 10 credits per page for Category A material the per-page credit for Category D has been set at 0.5.

Categories E and F differ somewhat in content but agree in their brevity; 86 per cent of 280 articles were under 6 pages and only 3 per cent were over 10 pages. These have been given 2 credits per page.

The ratings of the 60 scientists according to academic training and field of work (Table 3 and Figure 3) show clearly that those with the doctorate averaged considerably higher than those without. Thus 69 per cent of those without, rated less than 800 credits compared to only 14 per cent of those with the doctorate.

It is noteworthy that the anadromous non-doctorates rated very low. This is perhaps partially explained by their over preoccupation with the gathering of field data because of the pressure of management problems in Alaska and on the Columbia River. Data alone cannot answer questions. It must first be subjected to careful analysis.

Perhaps the chief difference between the production of the different groups lies in the approach. The first work on a new problem is usually exploratory in nature. Some investigators can never carry their problem past this stage because they are unable to form hypotheses concerning the problem. Or, if they form hypotheses, they attempt to prove their validity or invalidity with haphazardly collected data rather than through systematic observations predesigned for use in testing their hypotheses.

This difference of over two orders of magnitude in individual production is truly astonishing. How did it come about? What causes it to continue? And, what is the remedy?

The production of research results depends on at least five factors:

1. ABILITY. Research requires a special kind of ability. Many intelligent people are miscast in a research role because either they lack intellectual curiosity, or they are unable to do the concentrated disciplined thinking required.

2. TRAINING. Research requires good training. We cannot afford to start every problem with crude experiments and repeat every mistake of the past. Research requires a special type of training. Too many colleges are teaching men how to collect material and analyze it by already standardized techniques

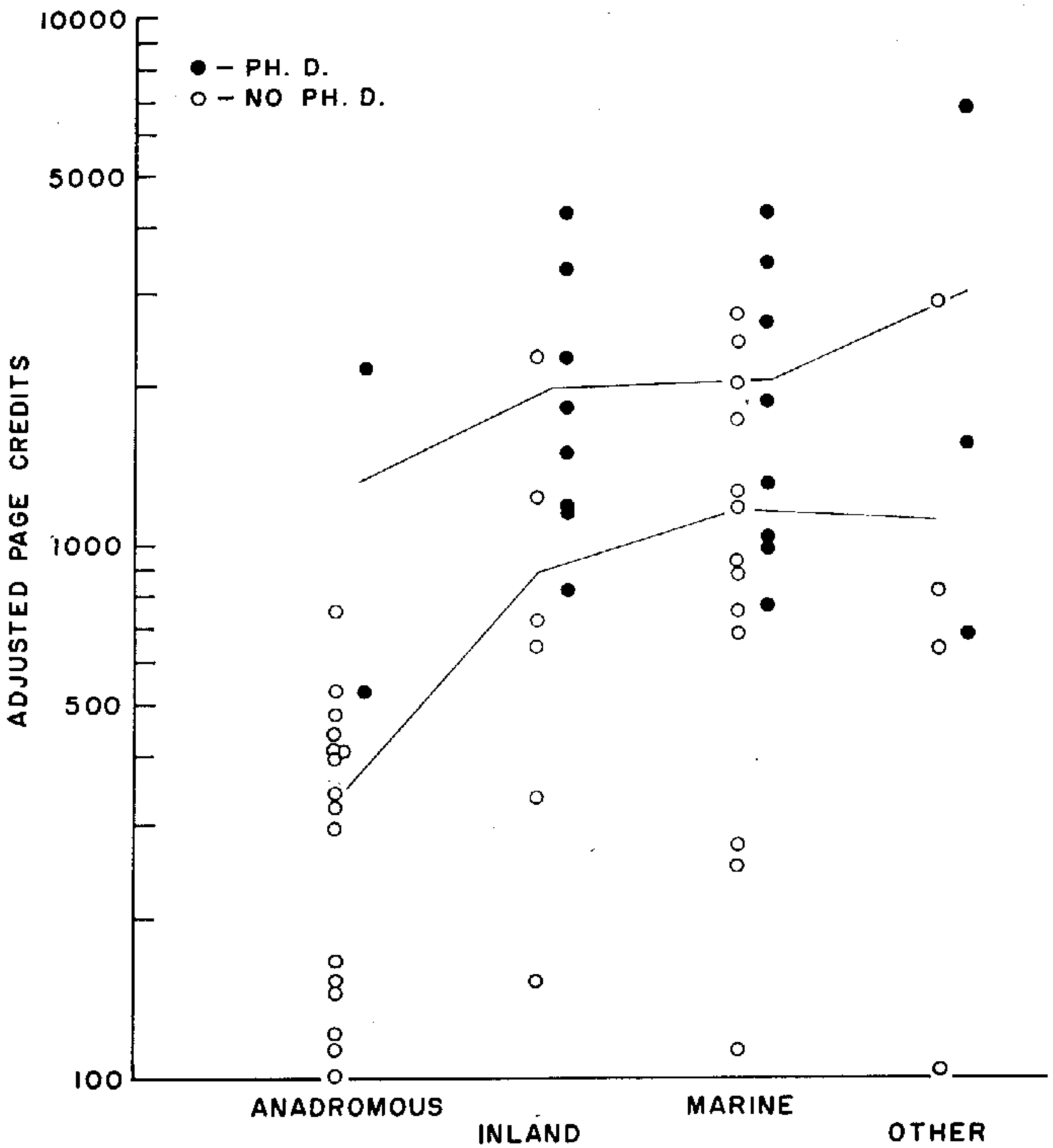

FIGURE 3. Page credits adjusted by categories, shown according to training and field of work, for the 17-year period.

without teaching how one goes about the intellectual probing necessary to solve a new problem. The result is the turning out of numbers of skilled workmen or technicians if you please. They are helpful up to a point, but many never achieve the ability to solve problems.

3. RESEARCH CLIMATE. This factor, often ignored, is of the greatest importance. Junior men of ability may wither or develop according to their scientific associations and the type of leadership furnished them. Junior men forced to work at lonely field stations often lose their interest at a time when stimulation is most needed.

4. PHYSICAL FACILITIES. Research is costly and requires the best of facilities. Carrying out a program of research without adequate physical facilities is not

economical. If facilities are inadequate for solution of a problem, it is wiser not to attempt it rather than to siphon off money always needed elsewhere. Striking examples of this lack are laboratories that are in reality only offices, with no provision for study of living material; research vessels that are cast-off hulls partially adapted for hydrographic research at great expense, yet not suitable for the job; and field stations so poorly devised for living that men spend precious time in merely managing to exist.

5. ADEQUATE STAFFING. It is essential that there be some relation between the size and training of the available staff and the problems they are expected to solve. If the staff is too small or lacks certain specialization, an effort should be made to reduce the immediate goals to those than can be met. An attempt to study at one time all ramifications of a large problem may be very frustrating. If a problem cannot be broken into small enough self-contained phases that can be tackled one at a time with reasonable assurance of progress, then the problem should be shelved until adequate staff is available.

We have noted the great range in apparent productivity of individual investigators and have discussed some of the factors involved. The obvious question posed is: Can some of these factors be changed so that production is increased? We believe they can.

Concerning the first factor, ability, we submit that since research is largely a mental process, it requires much higher than average intelligence. Out of the many workers hired, only a few are of research calibre. Yet because of the compartmentalization of an organization, a man hired to do research is continued in research even though it finally becomes apparent that his services could be more advantageously employed in other phases of conservation work. Part of the difficulty arises from the fact that an insufficient proportion of those of higher intelligence are attracted into research. Part of the problem arises from the fact that it is extremely difficult to judge during his first year as an investigator whether a man will turn into a research worker. After the first year, at which time he obtains permanent status in our Service, the tendency is to continue advancing a man without due regard for his productive capacity. Indeed, since it is normal for junior scientists to collect and compile data and work under rather immediate supervision, it may take some time before it is realized that he lacks originality or perhaps the ability to transpose ideas into actual reports. A weeding-out process for selection of those who should continue in research should be made at intermediate levels. Those not adapted to research should then be transferred to other activities. Most of these people are sincere, hard-working employees who can contribute in many fields but lack that certain quality demanded by research.

TRAINING is certainly an important factor in research. As shown in Figures 2 and 3, men with the doctorate averaged about twice as much in publication credit as those without. It will be noted, however, that in the marine field many without doctorates were close to the top. Many of these have had up to as much as two years of graduate training without taking a doctorate. There are thus indications that although good research men will perform well despite lack of graduate training, extra academic training confers a distinct advantage. Part of the reason for the higher average of those with doctorates may lie in the selection process of the universities themselves. Most universities of high standing accept only the better students as doctoral candidates, and many never succeed in attaining their degree. The Fish and Wildlife Service has recognized this need for advanced training in the program just adopted for permitting selected employees to attend universities for graduate work at Service expense.

RESEARCH CLIMATE is not easily defined but is a rather essential ingredient. A man of intellectual curiosity, given a challenging problem, adequate equipment and library facilities, and association with other research workers, will usually produce to the limit of his ability and training. The kindling and maintenance of genuine interest are greatly augmented by his associations. This is why a large group of researchers, containing specialists in several related disciplines, normally can boast of a higher production per man.

PHYSICAL FACILITIES are costly to acquire and maintain, yet without certain facilities some problems can never be solved. Because of the cost, it is not possible to equip an unlimited number of laboratories with seagoing vessels, adequate libraries, chemical and bacteriological laboratories, large sea-water systems, and reference collections. There is often pressure by well-meaning people to build new laboratories in new locations. In only a few specialized cases are these justified. The Fish and Wildlife Service now has a number of strategically located laboratories, and these should be fully equipped before any more are seriously considered. Furthermore, the overhead cost is proportionately much less on larger installations.

ADEQUATE STAFFING means that each problem studied should be assigned the number and type of personnel required. This presents many difficulties since some problems require specialists in very circumscribed fields. Where a problem promises to be of long duration, or at larger laboratories where problems of the same type are likely to recur, the hiring of specialists in narrow fields is often justified. For short-term problems the Fish and Wildlife Service has more recently met this problem through contract research with institutions having specialists in the required fields.

In summary, the analysis of publication records of 60 Fish and Wildlife Service scientists over a 17-year period shows a tremendous range in research production. A portion of this difference can be ascribed to the higher production rate of those with advanced academic training, and the lowered production of those closely associated with specific management responsibilities.

Suggested measures to raise production include the transfer of intermediate grade research employees who are low in research production into other fields of activity within the Service. The new Fish and Wildlife Service policy of providing opportunity for advanced academic training of selected employees is heartily endorsed. The provision and maintenance of adequate facilities by concentrating personnel in existing laboratories is recommended.